

Overview of the sea quark polarization measurements of PHENIX at RHIC



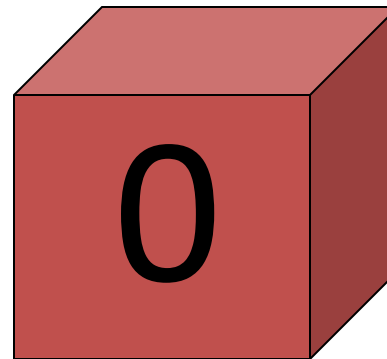
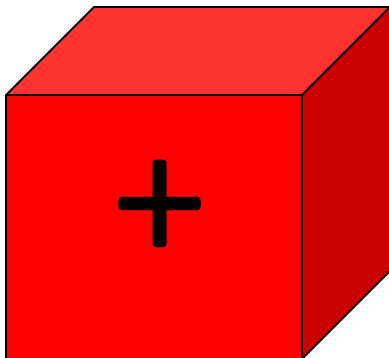
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on behalf of the PHENIX Collaboration

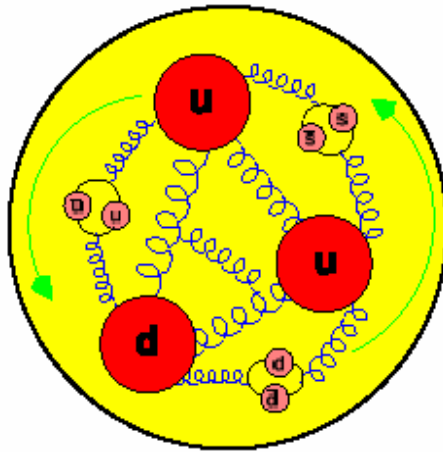


Nucleons

- Fundamental building blocks.
- Comes in 2 charges.
- Similar masses.



Internal Structure of the Proton



quark spin

orbital angular momentum

gluon spin

$$\frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_z$$

- The proton is a complex and composite structure.
- Internal structure includes quarks and gluons.
- Total spin is $\frac{1}{2} \hbar$.
- Spin is not simply the sum of the valence quark spins.

Outline

- Measurements that probe the spin structure of the proton.
 - Measurements made by PHENIX.
 - Future measurements PHENIX will make.
-
- Note: Limited to sea quark contribution to the spin structure only.

Spin Measurements

1. Polarized inclusive DIS measures:
 - Combination of valence and sea quark helicity distributions
 - Gluon helicity distributions
2. Polarized semi-inclusive DIS measures:
 - Individual flavored helicity distributions
 - But depend on fragmentation functions
3. Longitudinally polarized high energy proton collisions measures:
 - Individual flavored helicity distributions
 - Gluon helicity distributions
 - Free from uncertainties in fragmentation functions
 - High energy collisions mean that higher order QCD corrections can be calculated reliably.

Single Spin Asymmetries (A_L)

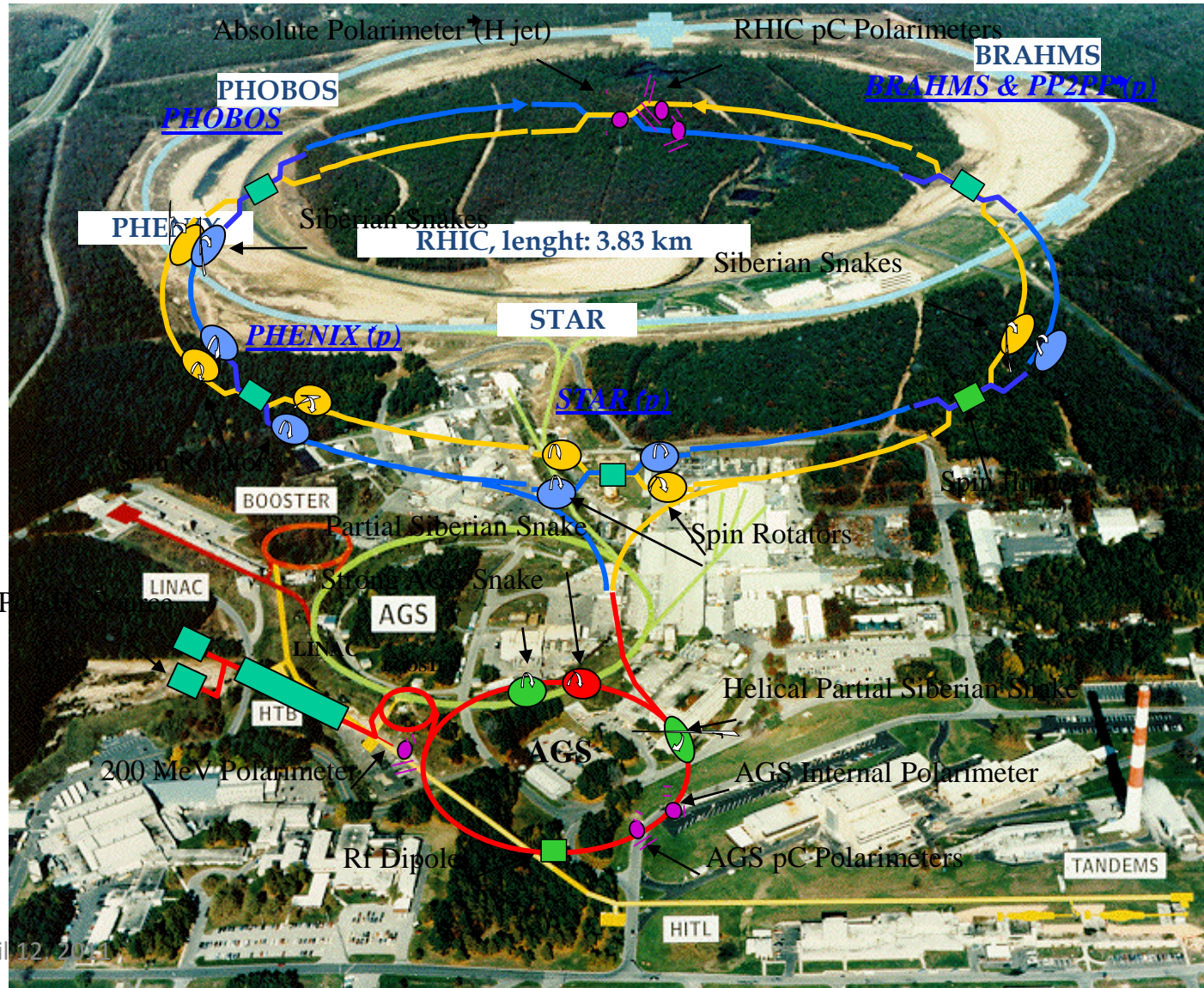
- W-Boson SSA (A_L^{W+}) probes sea and valence quark spin ($u + \bar{d} \rightarrow W^+$).
- W's couple only left-handed quarks with right-handed anti-quarks.
- Example at LO ignoring other quark contributions:

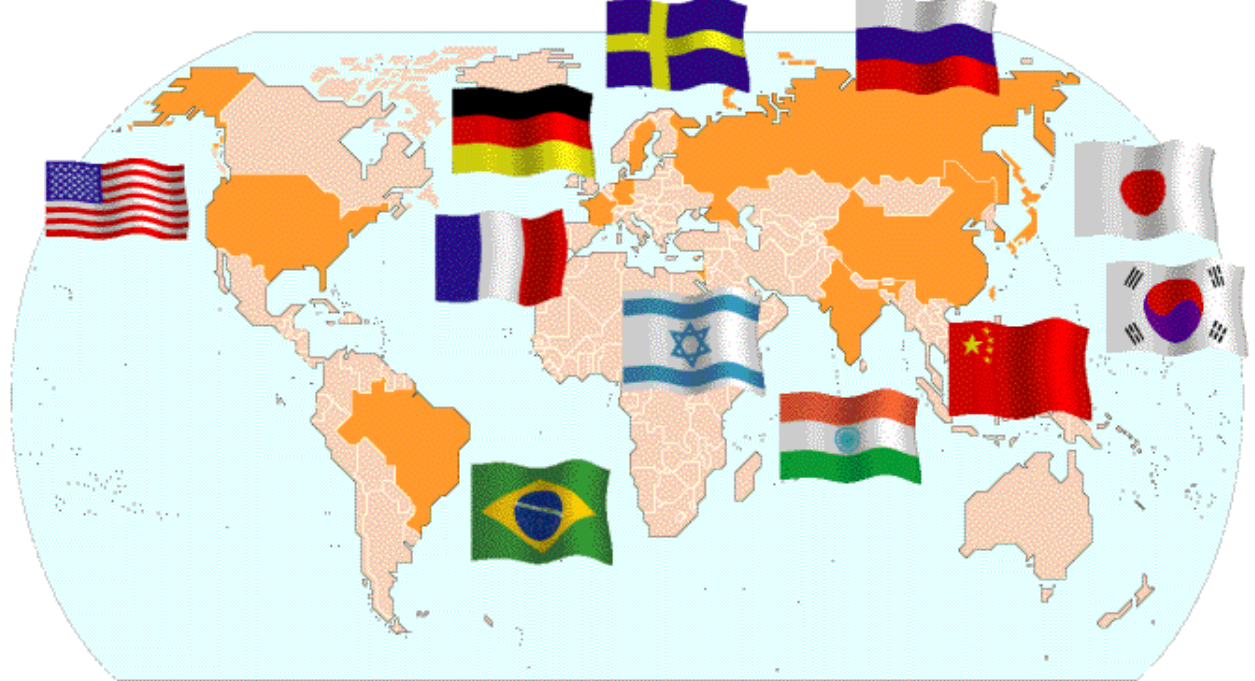
$$A_L^{W^+} = - \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

Bunce et al., Ann.Rev.Nucl.Part.Sci.50:525-575,2000

Relativistic Heavy Ion Collider (RHIC)

also collides polarized protons





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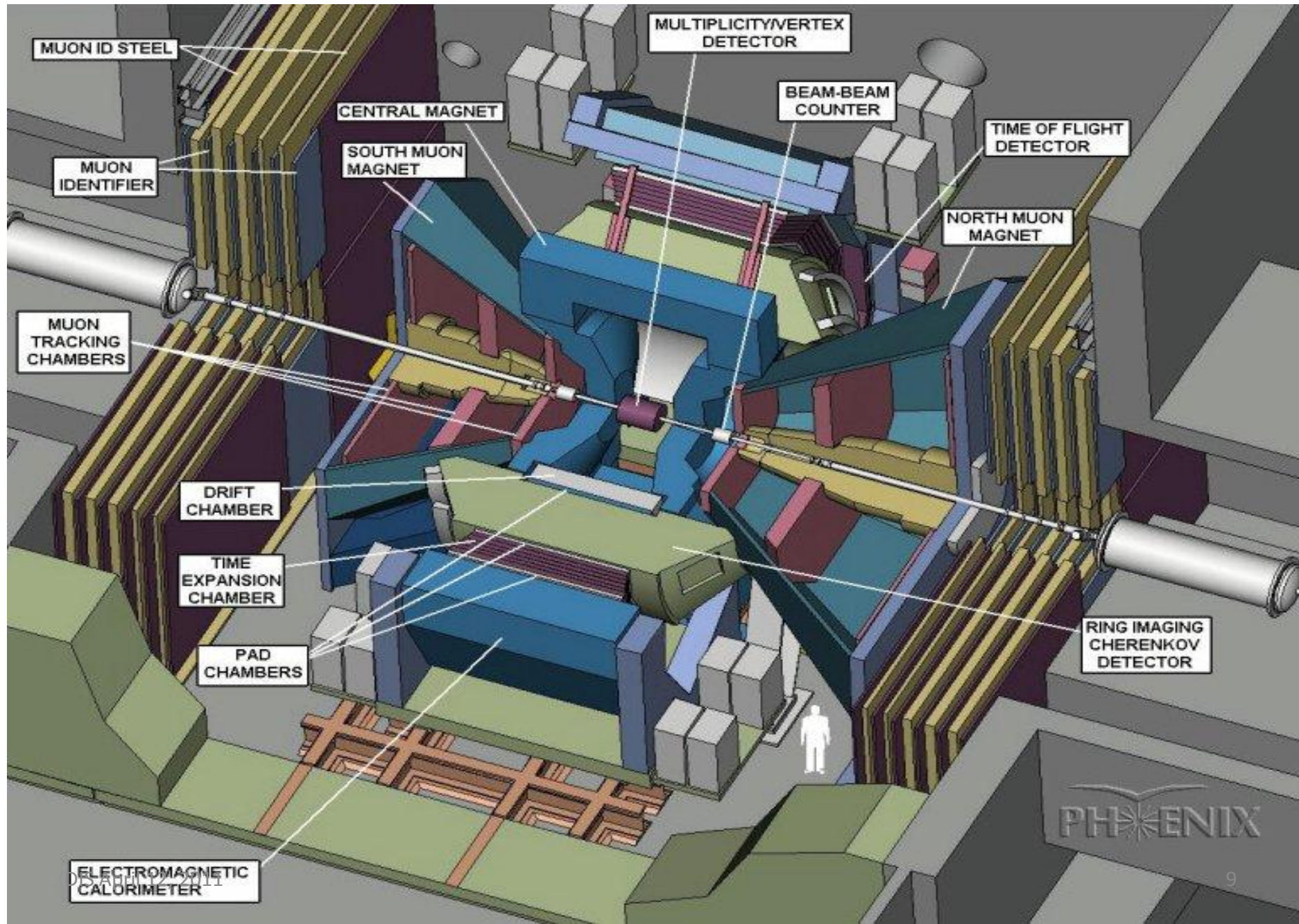
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The PHENIX Detector



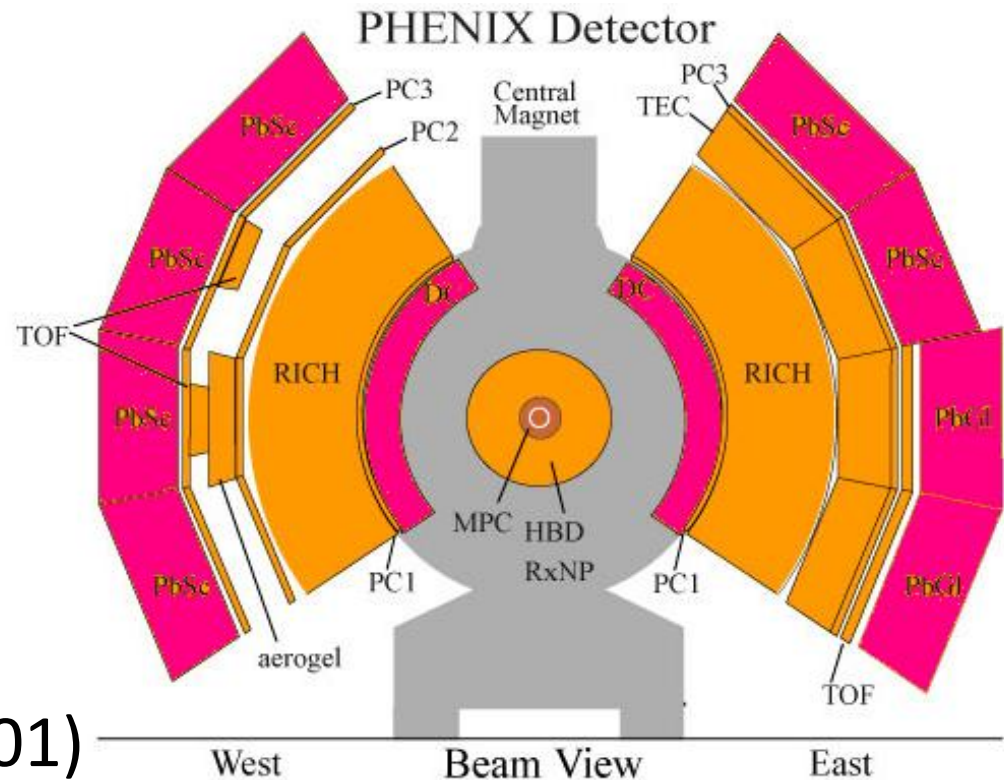
First W^\pm Measurement at RHIC

- RHIC provided enough polarized p+p collisions at $\sqrt{s} = 500$ GeV in 2009 for a first measurement.
- Yielded first W-Boson measurement for PHENIX.
[Phys. Rev. Lett. 106, 062001 \(2011\)](#)
- Integrated luminosity of 8.6 pb^{-1} .
- Average polarization was 39%.
- Preliminary results presented at DIS 2010.
- Limited to electron final state.

PHENIX: Electron Final State

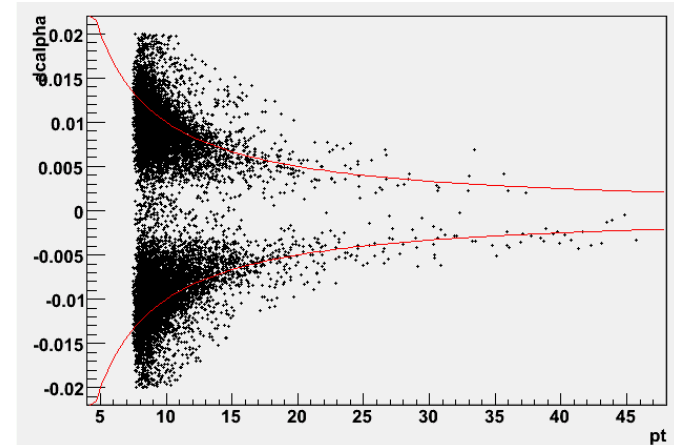
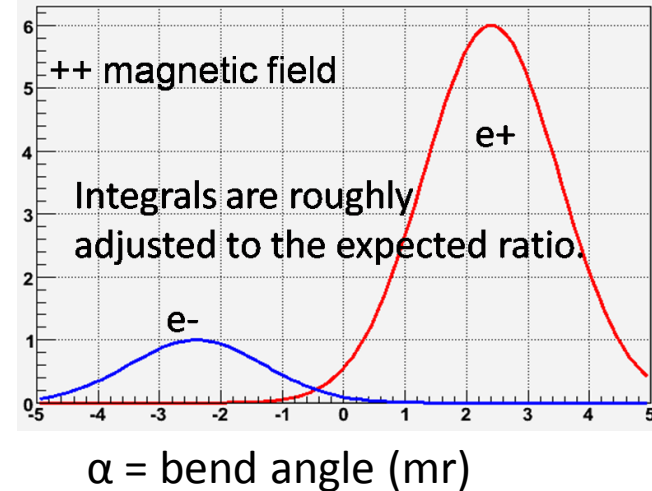
Central spectrometer arms

- $|\eta| < 0.35$
- $|\Delta\phi| < \pi/2$
- Tracking
 - Drift Chamber
 - Pad Chamber
- EM calorimeter
($\Delta\phi \times \Delta\eta \approx 0.01 \times 0.01$)
- trigger fully efficient
above ≈ 12 GeV



Event selection

- ± 30 cm vertex cut
- High energy EM Calorimeter clusters matched to charged track
- Loose timing cut eliminates cosmic rays
- Momentum resolution allows only loose E/p cut
- Charge sign discrimination by measuring bend angle in drift chamber



Longitudinal spin asymmetry A_L

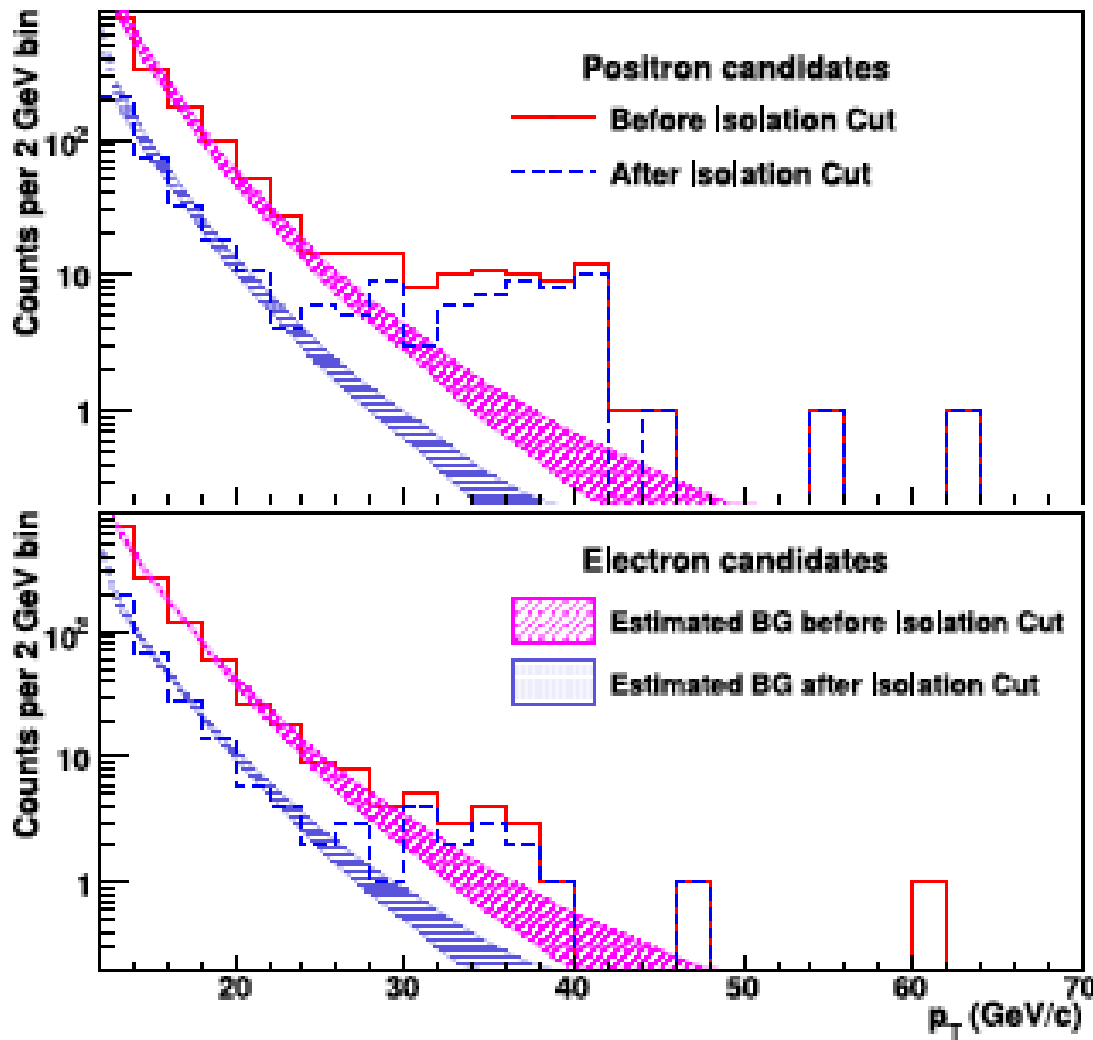
Parity violating longitudinal single spin asymmetry defined by

$$\epsilon_L = \frac{N^+ - R \cdot N^-}{N^+ + R \cdot N^-}$$

$$A_L = \frac{\epsilon_L \cdot D}{P}$$

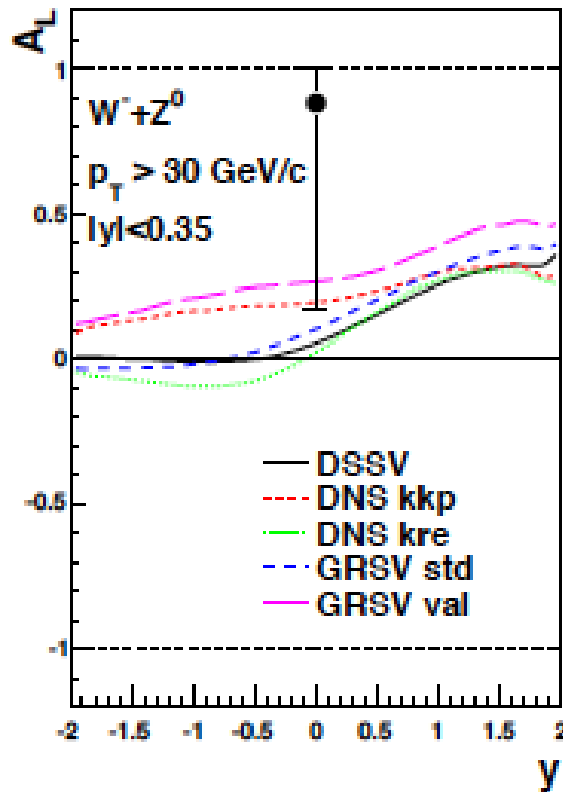
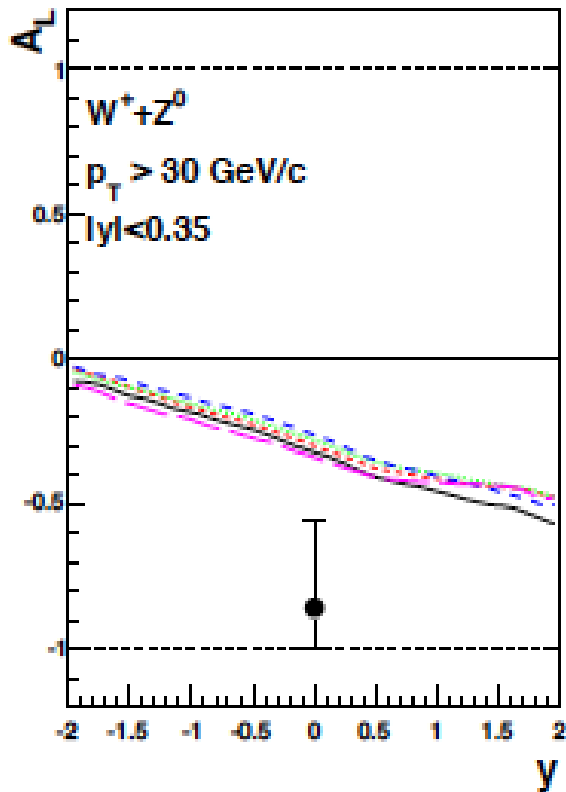
- N^+ = right handed production of W
- N^- = left handed production of W
- P = Polarization
- R = relative luminosities of the helicity states
- D = dilution by background and Z^0

positron & electron counts



- Isolation cut removes jets
- Background is reduced by about a factor of 4.
- About 20% of the signal is lost.

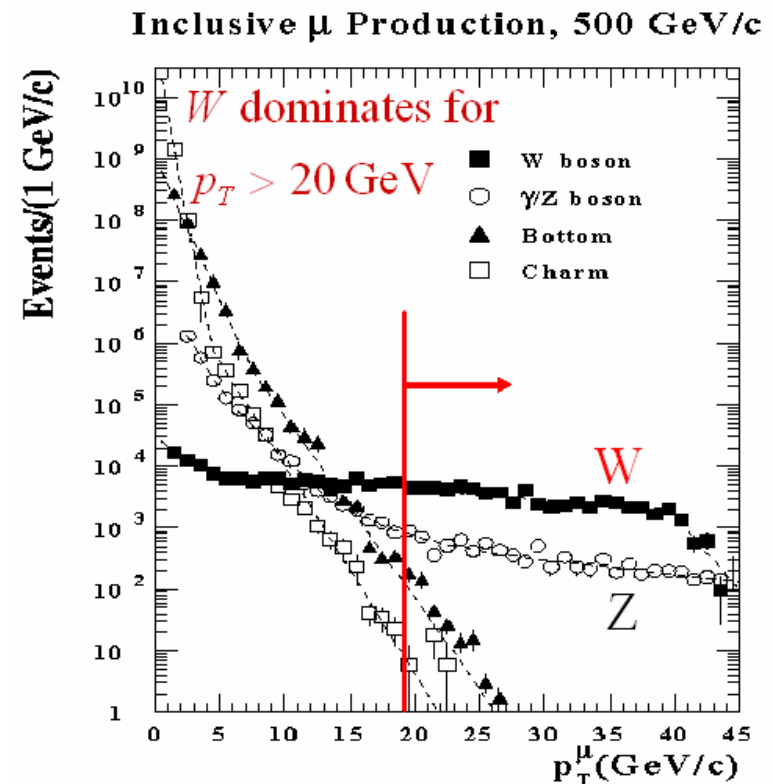
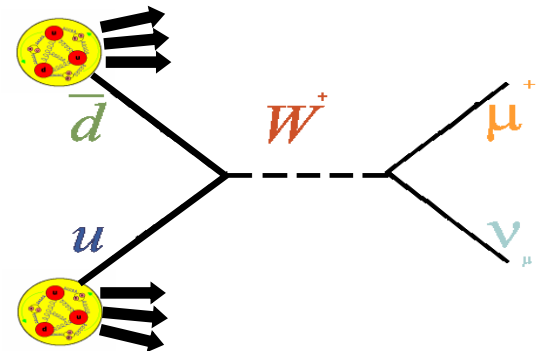
Longitudinal Single-Spin Asymmetries



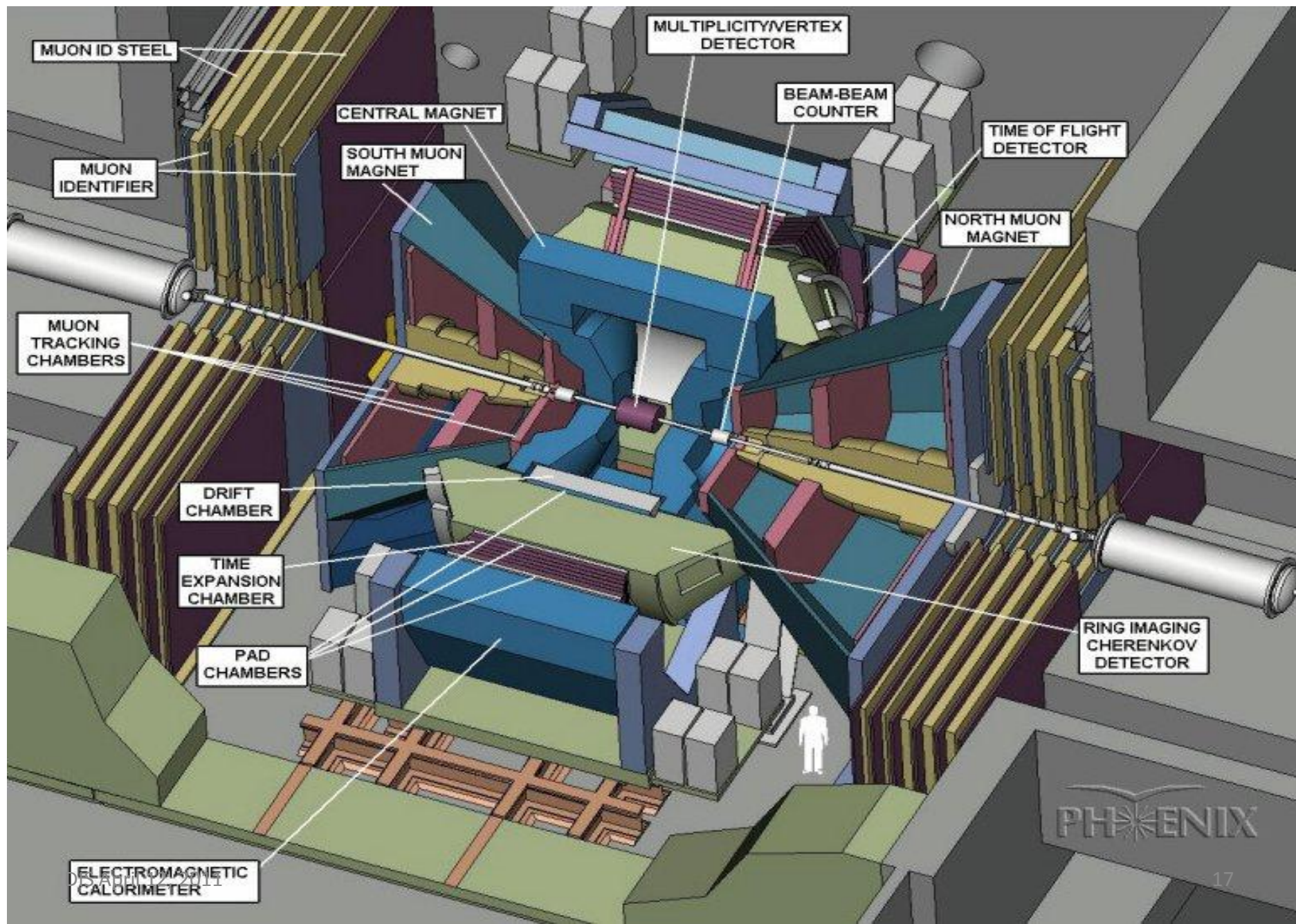
- Error bars represent 68% CL.
- Theoretical curves are calculated at NLO with different PDFs.

The Future

- More data
- Improved polarization
- Muon channel final state:
 - Need to at least increase rejection factor of muon arms trigger by a factor of ~ 100 .
 - We need a trigger that is sensitive to the muon momentum.
 - Need to introduce timing information in the muon trigger to reject beam backgrounds.



The PHENIX Detector



Forward Trigger Upgrade

1. Resistive Plate Chambers

- Provides rapid tracking information to the trigger.
- Timing information eliminates background from beam.

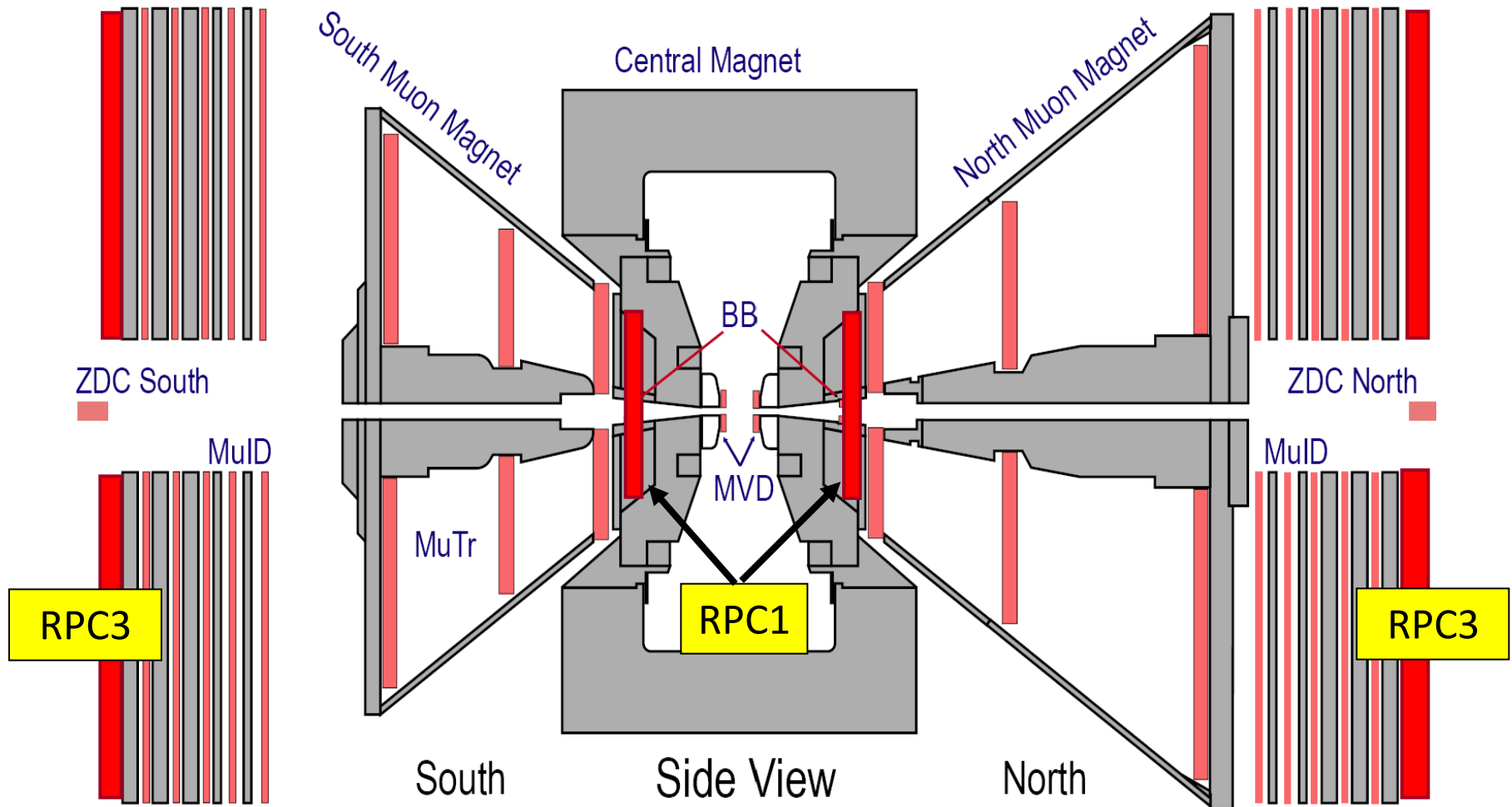
2. MuTr FEE upgrade

- Adds momentum information to the trigger.

3. Absorber material

- Helps to eliminate fake high p_T background

Scope of the PHENIX RPC Trigger Upgrade and Schedule



2010

DIS April 12, 2011

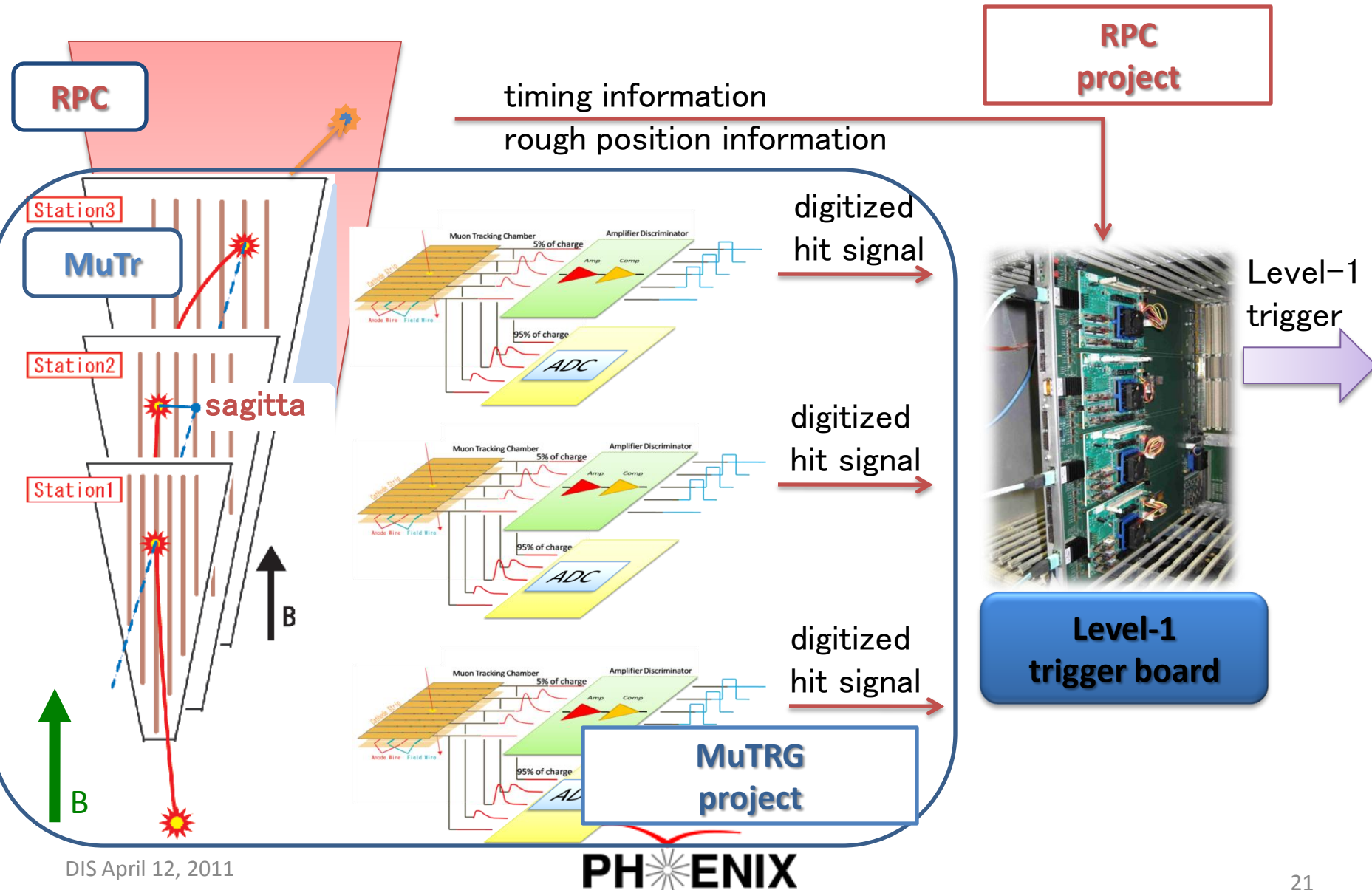


2009

RPC3 North and South Installed

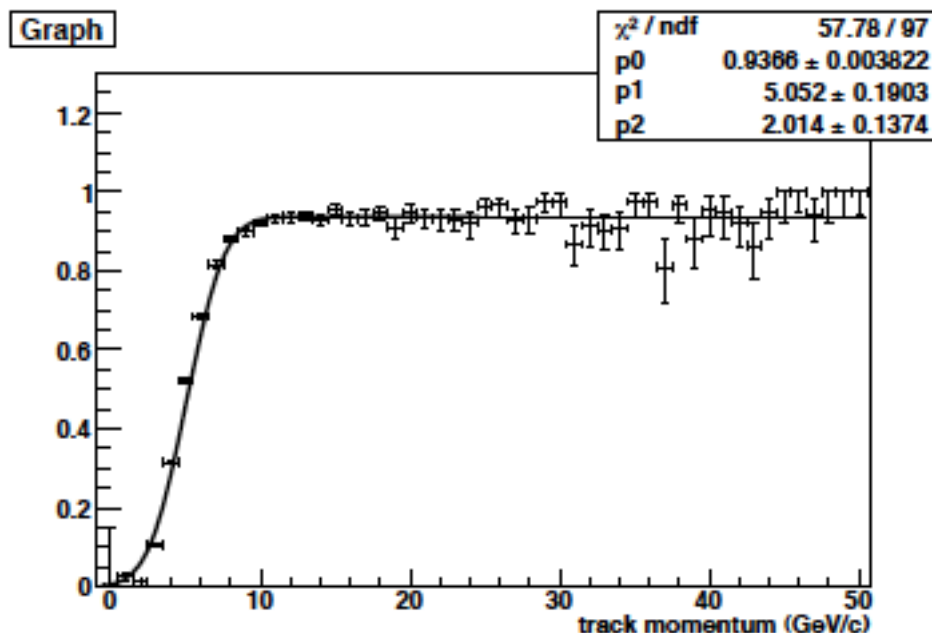


Forward Trigger Up grade

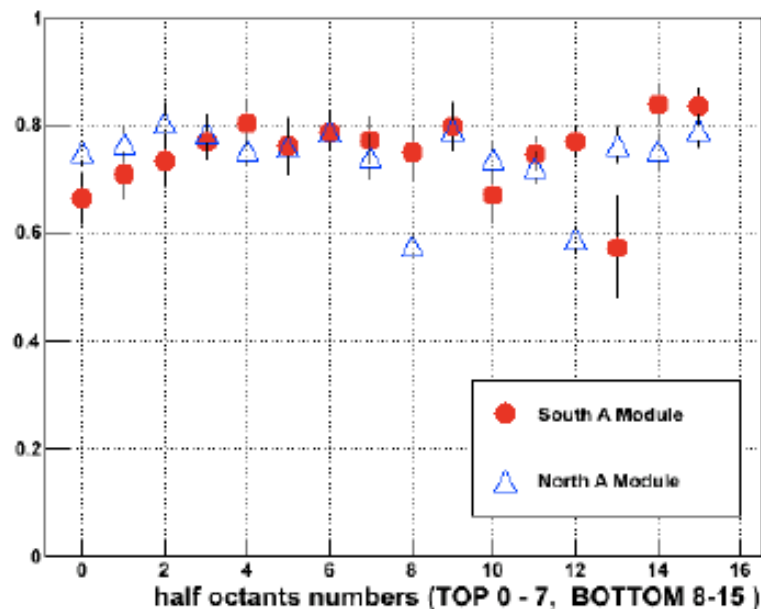


PHENIX Muon Trigger Performance

muTracker Trigger Efficiencies



RPC-Inner Ring Efficiency



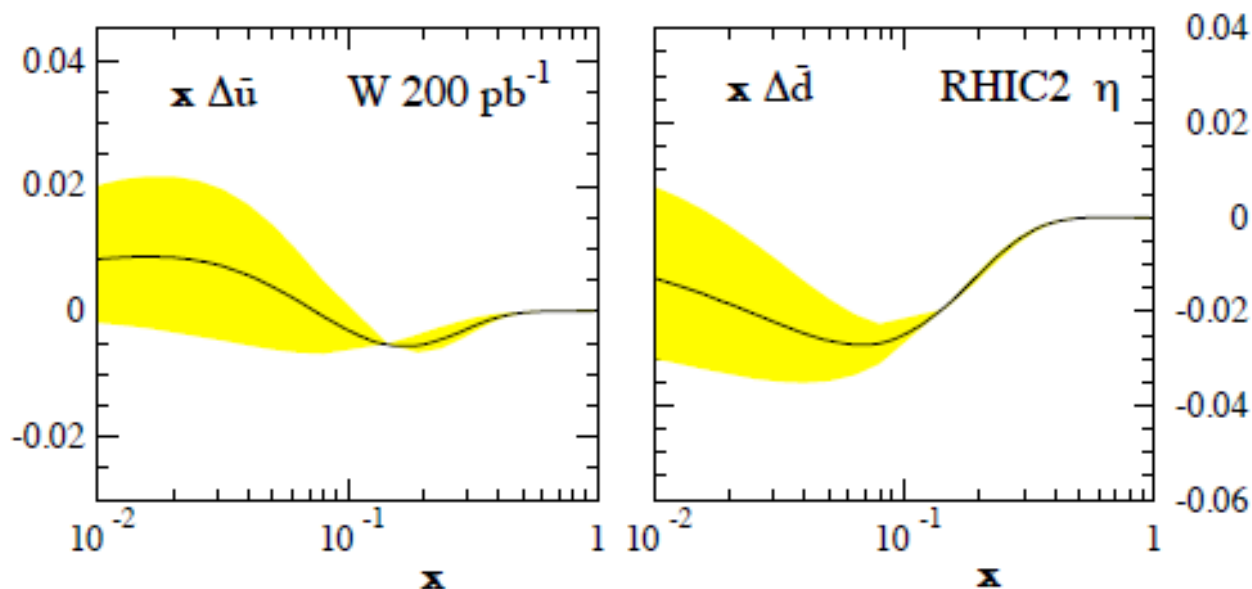
Problems Solved:

RPC-gas -> mixture & pressure differentials
timing -> RPCs now timed in correctly

Taking data with muTr part of trigger in run 2011, use RPC
offline for background rejection

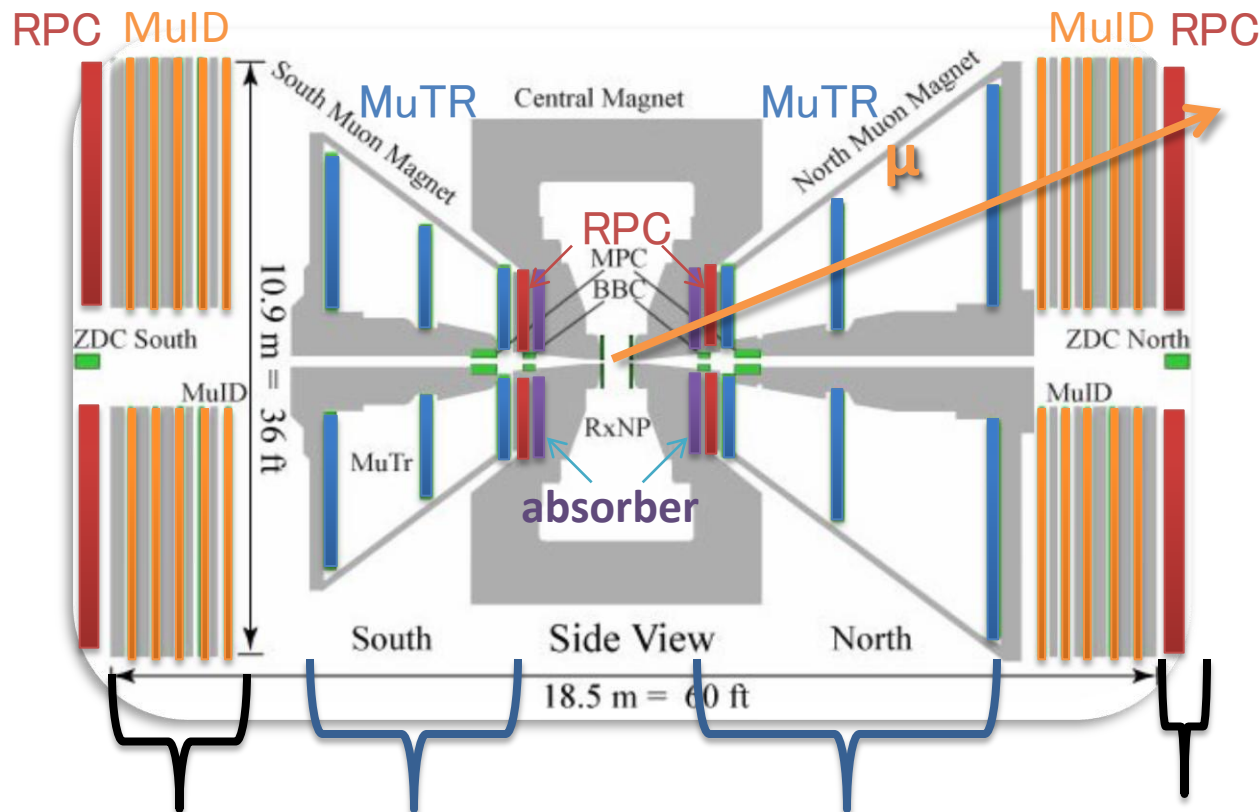
Summary

- W-boson measurements will improve our understanding of the quark/antiquark spin contribution to the proton.
- PHENIX's W-boson program is underway.
 - First electron results have been published.
 - A suite of upgrades is currently being commissioned that will yield the first muon result.



Backup Slides

PHENIX Muon Trigger Upgrade Project



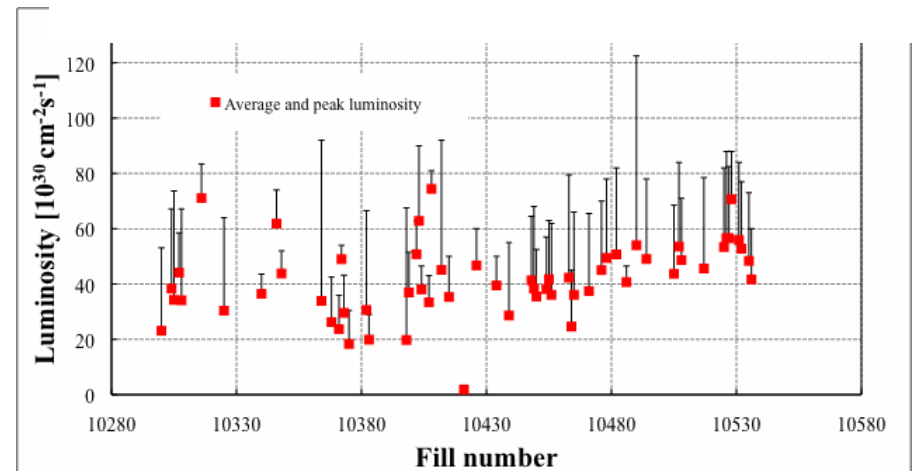
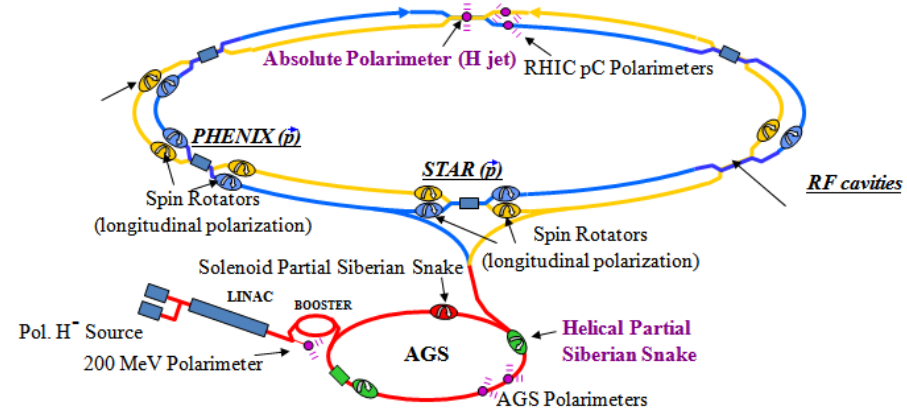
MuID trigger
selecting muon
momentum $> 2\text{GeV}/c$

MuTR FEE upgrade
fast selection of
high-momentum-tracks

RPC
provide timing information
and rough position information

RHIC Luminosity 2009

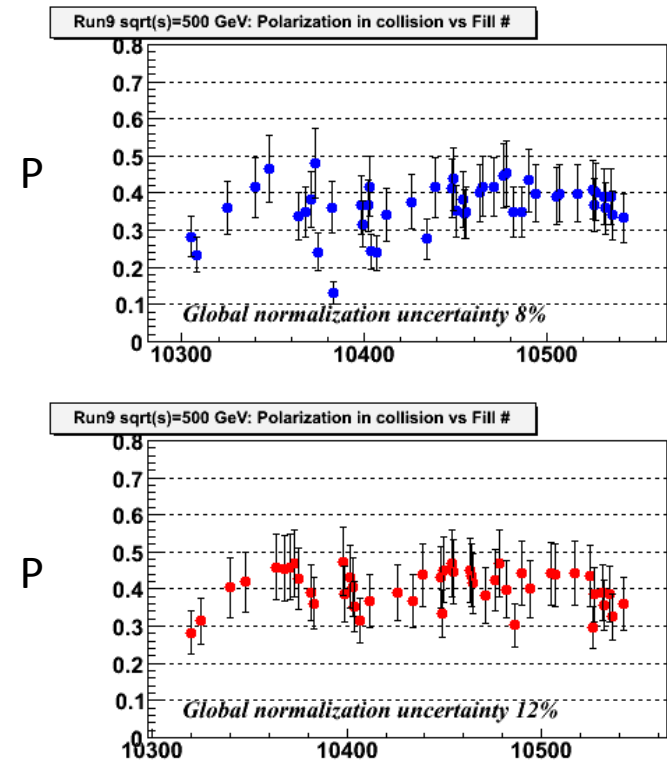
- Longitudinally polarized collisions at PHENIX and STAR
- Up to 111 bunch crossings with varied spin orientations for control of systematic errors
- Luminosity typically $\approx 4 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$



W. Fischer

2009 Polarization measurements

- Measured with two polarimeters
 - CNI polarimeter measurements available during run
 - H jet polarimeter provides absolute polarization
 - Measured residual polarization in real time after rotation at PHENIX



Polarization measured by CNI polarimeters fill-by-fill

PHENIX Detectors

π^0 , η , γ detection

- Electromagnetic Calorimeter (PbSc/PbGl):
 - High pT photon trigger
 - Acceptance: $|\eta| < 0.35$, $\phi = 2 \times \pi/2$
 - High granularity ($\sim 10 \times 10$ mrad²)

π^+/π^- , e , $J/\psi \rightarrow e^+e^-$

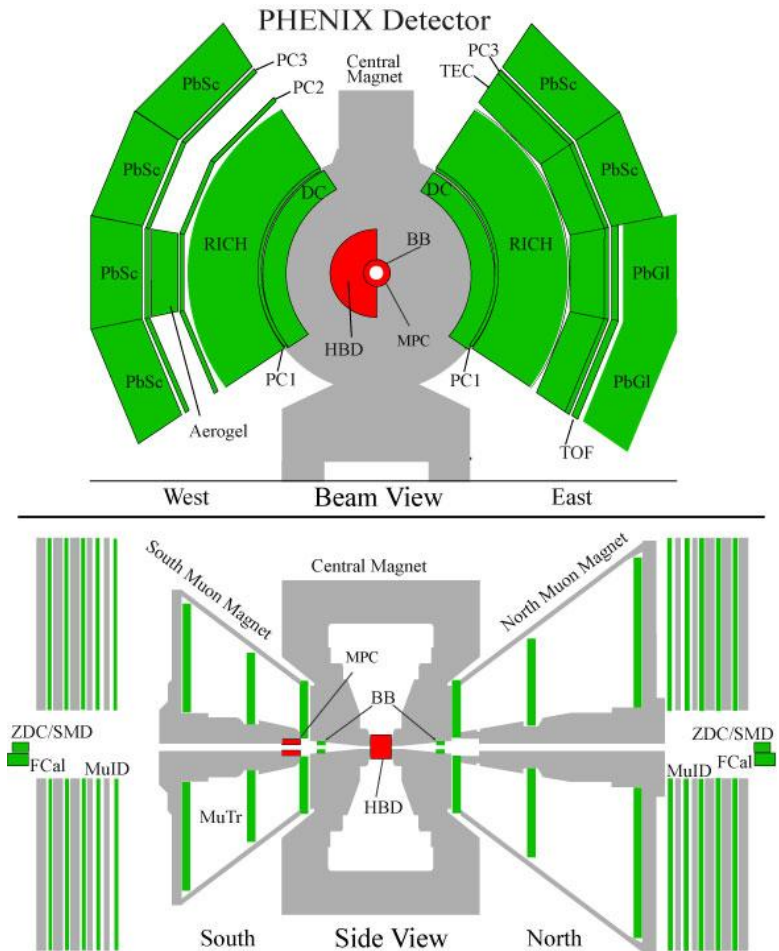
- Drift Chamber (DC)
- Ring Imaging Cherenkov Detector (RICH)

Relative Luminosity

- Beam Beam Counter (BBC)
 - Acceptance: $3.0 < \eta < 3.9$
- Zero Degree Calorimeter (ZDC)
 - Acceptance: ± 2 mrad about beam axis

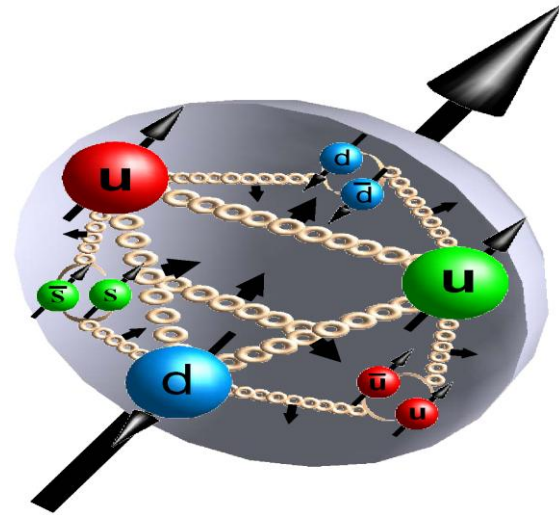
Focus : High granularity and high bandwidth

Compromise : Acceptance



Proton Spin

- Proton is a complex and composite structure of quarks and gluons with total spin of $\frac{1}{2} \hbar$
- Total spin of a composite structure is sum of individual components (spin and orbital angular momenta of quarks and gluons)
- Contribution of spin of all gluons in proton to the total spin of proton is ΔG (difference between same and opposite helicity gluons in polarized proton)

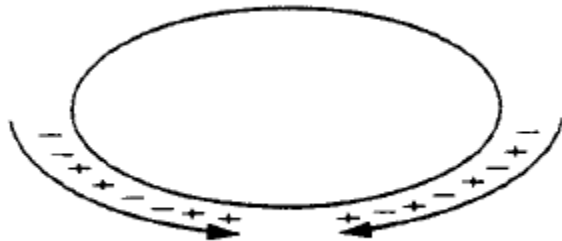


$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma(Q^2) + \Delta G(Q^2) + L_q(Q^2) + L_g(Q^2)$$

$$\Delta G = \int_0^1 dx \Delta g = \int_0^1 dx [g_+(x, \mu^2) - g_-(x, \mu^2)]$$

RHIC: Polarized p-p Collider / History

- Proton bunches filled with alternating spin combinations



- Four different spin patterns are used
- Siberian snakes rotate spin vector so that perturbations cancel on subsequent turns (spin is stable)
- Spin Rotators allow polarization to be set to longitudinal or horizontal as required
- Absolute (H-jet) and relative (pC) polarizations measurements

Longitudinal Spin Running in PHENIX

| Year | \sqrt{s} [GeV] | L [pb ⁻¹] (recorded) | Pol. [%] | FOM (P ⁴ L) |
|-------------|------------------|-------------------------------------|-----------|---------------------------|
| 2003 | 200 | 0.35 | 27 | 0.0019 |
| 2004 | 200 | 0.12 | 40 | 0.0031 |
| 2005 | 200 | 3.4 | 49 | 0.20 |
| 2006 | 200 | 7.5 | 57 | 0.79 |
| 2006 | 62.4 | 0.08 | 48 | 0.0042 |
| 2009 | 200 | 14 | 57 | 1.5 |
| 2009 | 500 | 14 | 39 | 0.21 |